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SIX-LINK VARIABLE-STROKE ENGINE MECHANISMS WITH ONE PRISMATIC JOINT

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Abstract - The author determines the distinct mechanisms from Watt and Stephenson's kinematic chains by assuming all th joints as revolute joints and later draws the same to get variable stroke engine mechanisms by replacing one revolute joint with prismatic one. By doing so, the need of throttling or pumping losses may be eliminated and as a result the engine efficiency may be increased. The paper theme is based on theoretic approach and extremely useful for P.G students, research scholar and design engineer in the conceptual stage of design of engine mechanisms.

Keywords - Mechanism, Variable Stroke, Degree of Freedom

I. INTRODUCTION

Generally we use slider crank mechanism of constant stroke length in most of the internal combustion engines. As per a computer simulation, the economy of an engine of variable-stroke may be increased by 20% [1]. In short stroke operations, there is reduction in pumping losses and reduction in engine friction [2-3].The second reason is because of reduction in engine friction under short stroke operations [2, 3].For proper functioning of variable stroke engine, the mechanism should have nearly a constant compression ratio, constant phase angle relation between the T.D.C.(Top Dead Center) position of piston and crank angle and time required a few tenths of a second as the stoke length changes. Theoretically, there should be 2 degree of freedom of variable stroke mechanisms (One needed to convert reciprocating motion of piston into rotary motion of crank shaft and another for stroke length adjustment). The second dof is obtained by moving a chosen fixed pivot of one dof mechanisms. Therefore, the frame or engine block must be a ternary link whose one joint will work as a pivot, second joint will connect the piston and third joint connect to the crank shaft [4]. We assume that there are only one prismatic and all other revolute joints in the mechanisms. Structural analysis and synthesis of mechanism is very important for the invention and innovation of mechanism. Undetected isomorphism results in duplicate solutions and unnecessary effort. Falsely identified isomorphism eliminates possible candidates for new mechanisms. Identifying isomorphism of kinematic chain by using characteristic polynomial method is a simple method but the reliability of such methods was in question, as several counter examples were found [5]. Some new approaches to these problems were also investigated such as Eigen vector [6], incident degree [7, 11], group theory [8,9], adjacent-chain table [10], artificial neural network [12].

However, most of these methods are complex and difficult to grasp and utilize. Also, there is a lack of uniqueness or it takes too much time for determining isomorphism of a kinematic chain. Therefore, in this paper, a new method [JJ] matrix [13] to characterize the mechanism kinematic chains is presented by considering the revolue and prismatic pairs. Critical study of kinematic and machine performance has revealed that the performance of joints is affected by the type of pair and coefficient of friction.

II. METHODOLOGY

It may be mentioned here that links and joints of a chain are arbitrarily labeled. The degree of link actually represents the type of link like binary, ternary, quaternary etc. Let the degree of i^{th} link in a kinematic chain be designed as d (l_i).d (l_i) =2, for binary link,d (l_i) =3, for ternary link, d (l_i) = 4, for quarter nary link, d (l_i) =k, for k-nary link.The Joint-Joint [JJ] Matrix is used. This matrix is based upon the connectivity of the joints through the links and defined, as a square symmetric matrix of size n x n, where n is the number of joints in a kinematic chain.

$$[JJ] = \left\{ L_{ij} \right\}_{n \times n} \quad \text{---------} \quad (1)$$

Where

$$L_{ij} \left\{ \begin{array}{l} = \text{Degree of link between } i^{th} \text{ and } j^{th} \text{ joints} \\ \text{those are directly connected} \\ =0, \text{ if joint i is not directly connected to joint j} \\ \text{Off course all the diagonal elements } L_{ii} = 0 \end{array} \right\}$$

If in the [JJ] matrix, the diagonal elements of the corresponding joints of the fixed link-'a' are changed from 0 to 1 (zero to one), it will be the representation of the first mechanism with fixed link 'a'. Then this new [JJ] matrix is represented by [JJ-a] matrix. The structural invariants of this [JJ-a] matrix are then calculated using software MAT LAB. These invariants 'SCPC-a' and 'MCPC-a' are the characteristic numbers of the first mechanism. This process is repeated for the second link 'b' and so on. In this way, a set of invariants equal to the number of the links are obtained. Some of them may be same and others are different. The same structural invariants represent the corresponding structurally equivalent links that constitute one DM.

III. ILLUSTRATIVE EXAMPLE

We consider two kinematic chains with 6 bars, 7 joints, and single degree of freedom as shown in Figure-1.

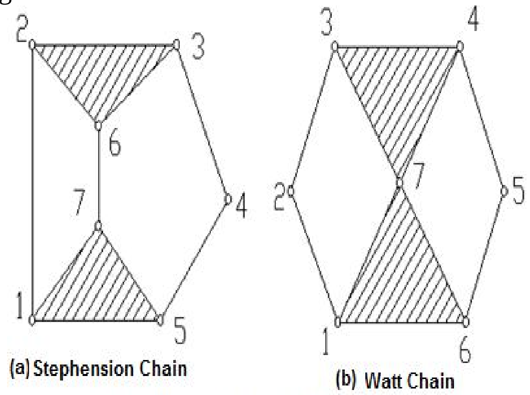

Figure-1: Six link single degree of freedom Kinematic chain

The task is to examine whether these two chains are isomorphic and determine the distinct mechanisms from these two kinematic chains. The values of structural invariants are as follows: For chain 1(a): [SCPC] = 5.2200e+003 , [MCPC] =3.1680e+003 and For chain 1(b): [SCPC] = 8.9280e+003 , [MCPC] = 3.3000e+003. Our method reports that chain 1(a) and 1(b) are non-isomorphic as the set of values of [SCPC] and [MCPC] are different for both the kinematic chains. Note that by using other method, the same conclusion is obtained.
Now we have to determine the distinct mechanisms from the above two kinematic chains.
Considering the kinematic chain with 6-links, 7-joints, 1-degree of freedom Stephenson's chain as shown in Figure-1 (a). The [JJ] matrix representing the kinematic chain [Figure 1(a)] using equation (1) is represented as[JS].

$$JS=\begin{pmatrix} 0 & 3 & 0 & 0 & 2 & 0 & 3 \\ 3 & 0 & 2 & 0 & 0 & 0 & 3 \\ 0 & 2 & 0 & 3 & 0 & 3 & 0 \\ 0 & 0 & 3 & 0 & 2 & 3 & 0 \\ 2 & 0 & 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 3 & 3 & 0 & 0 & 2 \\ 3 & 3 & 0 & 0 & 0 & 2 & 0 \end{pmatrix}$$

The set of structural invariants are derived from the [JS] matrix using software MAT LAB. The structural invariants of the mechanisms derived from the kinematic chain Figure 1 (a) obtained from [JJ-a], [JJ-b], [JJ-c], etc are :SCPC (JSa) = 12280,SCPC (JSb) = 7.1960e+003 , SCPC (JSc) = 8.0320e+003,SCPC (JSd) = 7.1960e+003,SCPC (JSe) = 1.2280e+004,SCPC (JSf) = 8.0320e+003,MCPC (JSa) = 4.8500e+003,MCPC (JSb) = 3.1920e+003,MCPC (JSc) = 3.1110 e +003,MCPC (JSd) = 3.1920e+003,MCPC (JSe) = 4.8500e+003,MCPC (JSf) = 3.1110e+003,
Observing the structural invariants for the above six mechanisms, it is found that the structural invariants of link 'a' and 'e' are same. Hence, they are treated as equivalent links and form only one distinct mechanism. Similarly, the structural invariants of link 'b' and'd' are same, hence form second distinct mechanisms. In the similar way link 'c' and 'f' form third distinct mechanisms. Therefore, 3 distinct mechanisms are obtained from kinematic chain shown in Figure 1 (a). Following the above said procedure, we obtain 2 distinct mechanisms for kinematic chain [Watt chain] with 6 bars, 7 joints, and single degree of freedom as shown in Figure 1 (b). The total distinct mechanisms obtained from kinematic chains shown in Figure-1 are 5. Here we considered that all the joints are revolute joints and ternary as well as binary links are fixed alternatively. But when only ternary link are to be made as cylinder block (fixed) practically then we will get only four mechanisms as there are only four ternary links in total. we draw one of the ternary links as the fixed link and one of the ground connected joints as the prismatic joint , we obtain four distinct mechanisms that are given in Figure 2. Note that if we allow the maximum number of prismatic joints to be two with the condition that no link can contain more than one prismatic joint, the number of non isomorphic mechanism structures increases to 16 [14].

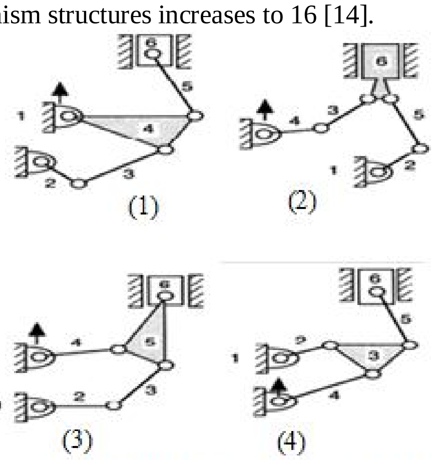

Figure-2: Variable stroke mechanisms derived from Watt and Stephenson chain with one prismatic joint

IV. RESULT AND DISCUSSION

Theoretically, when we considered all the joints are revolute joints the total distinct mechanisms achieved from kinematic chains [Stephenson and Watt chains] shown in Figure-1 are 5. But when practically, we draw one of the ternary links as the fixed link and one of the ground connected joints as the prismatic joint , we obtain four distinct mechanisms that are given in Figure-2. So, it is clear that the results given in the literature of isomorphism and distinct mechanisms are true only theoretically if all the joints are considered revolute. In actual practice, it is not possible that in any mechanism can have all revolute joints. It is also possible that all the distinct mechanisms obtained by considering the actual lower and higher pairs may not be feasible. Here, we see that the piston and the crankshaft of the second variable stroke mechanism (2) in Figure 2 has four-bar loop. A change in the location of the adjustable pivot does not have any effect on the stroke length [4]. Therefore, this mechanism is not feasible while the other three mechanisms are feasible solutions. Also, if we take 2 prismatic joints with the condition that no link can contain more than one prismatic joint, the number of distinct mechanism are increases to 16 [14].

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